# **Understanding Heart Murmurs in Golden Retriever Puppies**

#### Introduction

Heart murmurs in puppies can be a source of anxiety for new owners and a diagnostic challenge for veterinarians. This comprehensive guide is designed to demystify heart murmurs in Golden Retriever puppies, providing clear explanations of the science in plain language. The goal is to equip families, veterinary professionals, and researchers with knowledge about what heart murmurs are, why they occur, how to evaluate them, and what they mean for Golden Retrievers. Golden Retrievers are an affectionate and popular breed, but like many large breeds they have certain predispositions to heart conditions. Early understanding and proper action can make a significant difference in the health and well-being of affected puppies.

In the sections that follow, we will explore the fundamentals of heart murmurs and heart function, discuss how common murmurs are in puppies (particularly in Golden Retrievers) and the various reasons they occur, distinguish between harmless "innocent" murmurs and those signaling congenital heart disease, and outline the steps for diagnosis and management. We will also delve into considerations specific to breeders (including screening protocols and ethical decisions) and summarize what is known about the genetic basis of heart defects in Golden Retrievers, especially subvalvular aortic stenosis (SAS). Finally, key takeaways and future directions will be presented to guide readers in applying this knowledge and recognizing areas where further research is needed.

By combining accessible explanations with detailed veterinary insight, this guide aims to be a valuable resource whether you are a puppy owner seeking reassurance, a breeder making responsible decisions, a veterinarian sharpening your diagnostic approach, or a researcher investigating canine cardiac health.

#### What is a Heart Murmur? - Definition, Hemodynamics, and Significance

A **heart murmur** is an abnormal sound made by blood flow within the heart or nearby large vessels, heard via a stethoscope as a "whooshing" or rushing noise between the normal heartbeats. Normally, blood flows through the heart in a smooth, laminar way that produces almost no sound except the familiar "lub-dub" of valve closures. A murmur occurs when that blood flow becomes **turbulent** – comparable to water flowing rapidly through a narrow or uneven channel – creating vibrations that we can hear. The science of blood flow through the heart and vessels is called **hemodynamics**, and even subtle changes in hemodynamics can lead to murmurs in small animals like puppies.

**How Murmurs Are Produced:** Turbulent flow can arise for several reasons. It may occur if there is a narrowing or obstruction in one of the heart valves or vessels, if there is a leak or hole that causes blood to flow in the wrong direction, or if the blood is flowing especially fast or has altered properties (such as lower viscosity). In puppies, the heart is small and beating quickly, so even normal blood flow can sometimes generate mild turbulence. The intensity (loudness) of a murmur generally reflects how much turbulence is present, but an important point is that louder doesn't always mean more dangerous – a small harmless defect can create a loud noise, while a very severe problem might sometimes produce a softer murmur. The **location in the cardiac cycle** where the murmur is heard is also telling: most common murmurs in puppies happen during the pumping phase of the heartbeat (**systolic murmurs**, between the "lub" and "dub"), whereas murmurs during the filling phase (**diastolic murmurs**) or continuous throughout the cycle are rarer and often indicate specific problems.

**Normal Heart Sounds vs. Murmurs:** To appreciate what a murmur signifies, it helps to know the basics of normal heart function. The canine heart has four chambers (two atria and two ventricles) and four valves (tricuspid, pulmonic, mitral, and aortic). In a normal heartbeat, valves snap shut to produce the clear "lub" (first heart sound, when the tricuspid and mitral valves close as the ventricles begin to contract) and "dub" (second heart sound, when the aortic and pulmonic valves close after the ventricles have pumped blood out). Between these sounds, blood is flowing forward through the open valves smoothly. A murmur indicates that somewhere during this cycle, smooth flow is disrupted – perhaps a valve isn't opening wide enough, a valve isn't closing properly and leaking, a vessel is narrowed, or there's an abnormal opening between chambers.

**Significance in Puppies:** In pediatric veterinary care, detecting a murmur in a puppy is significant because it can be the first clue to a congenital heart defect. Just as in human infants, some puppies are born with structural heart abnormalities that can affect their health. Early detection allows for timely intervention or management – for example, some defects might be corrected with surgery, and often treatment needs to be performed early before the puppy develops heart failure or other complications. However, not all murmurs in puppies spell disaster. Many young puppies – especially those of larger breeds like Golden Retrievers – can have innocent murmurs that they eventually outgrow. These benign murmurs arise not from disease but from the normal physiology of a growing puppy's cardiovascular system (for instance, the heart pumping vigorously in a small chest, or normal changes in blood composition after birth). Distinguishing between a harmless murmur and a worrisome one is a critical part of veterinary care for the young animal.

**Breed Predisposition – Relevance to Golden Retrievers:** Golden Retrievers are known to be a generally healthy breed, but they do have some breed-specific predispositions in the cardiac realm. Most notably, Golden Retrievers (along with other

large breeds like Rottweilers and Newfoundlands) have a higher incidence of a congenital condition called **subvalvular aortic stenosis (SAS)**. SAS is a hereditary narrowing just below the aortic valve, and it is one of the most common congenital heart diseases in Goldens. A puppy with developing SAS often will have a heart murmur detectable on examination. Therefore, the presence of a murmur in a Golden Retriever puppy carries particular importance – it could be the benign murmur of a healthy, growing pup, but it might also be an early red flag for SAS or another cardiac issue. Being aware of breed tendencies helps veterinarians and breeders remain vigilant. It means that when a Golden Retriever puppy has a murmur, there is a higher index of suspicion to investigate for conditions like SAS. Conversely, it also means families adopting a Golden should be informed that murmur checks are a routine part of puppy health exams due to this predisposition.

In summary, a heart murmur is simply a noise caused by turbulent blood flow, but its implications range from completely innocent to clinically significant. In any puppy, and especially in breeds like the Golden Retriever, careful evaluation of a murmur is needed to understand the hemodynamic reason behind it and to determine if it signals an underlying problem requiring attention. In the next section, we will look at how common heart murmurs are in puppies (particularly in Golden Retrievers) and why the timing of their appearance can vary.

#### Epidemiology and Prevalence of Heart Murmurs in Golden Retriever Puppies

When you first learn that your Golden Retriever puppy has a heart murmur, a natural question is, "How common is this, and what are the chances it's something serious?" The term **epidemiology** refers to the study of how often diseases or conditions occur in different populations. For heart murmurs in puppies, epidemiological data give us insight into how frequently murmurs are detected and what proportion of those might correspond to actual heart disease.

**Prevalence of Murmurs in Puppies:** It might be surprising to learn that soft heart murmurs are quite frequent in young puppies. Roughly one out of every four puppies under six months of age can have an audible murmur at some point, even if they are perfectly healthy. In some breeds, the prevalence is even higher – for instance, very athletic or slender breeds (like whippets) often show murmurs in well over half of the puppies. Golden Retriever puppies, being a larger breed, also commonly exhibit these transient newborn murmurs. A breeder or veterinarian examining a litter of Golden pups at 6–8 weeks old might find a low-grade murmur in several of them. This does not mean that 25–50% of Golden Retrievers have heart disease; instead, many of these murmurs are **innocent murmurs** that will disappear as the puppy grows (we will detail innocent murmurs in Part III). Studies have shown that a significant portion of normal puppies

have murmurs that are present at their early veterinary checks but no longer detectable by the time they reach 4 to 6 months of age.

**Prevalence of Congenital Heart Disease:** True congenital heart defects (structural heart problems present from birth) are much less common than innocent murmurs. In the general dog population, congenital heart disease is estimated to affect well under 1% of all dogs. However, this risk is not evenly distributed among breeds. Some breeds have higher incidences of certain defects. Golden Retrievers, for example, are overrepresented among cases of subvalvular aortic stenosis (SAS). While an exact percentage of Goldens affected by SAS is hard to pinpoint (because many cases are mild and may go undiagnosed), it is recognized as the breed's most prevalent congenital cardiac issue. Other heart defects like patent ductus arteriosus (PDA) or pulmonic stenosis (PS) are more common in other breeds, but they can still occur in Goldens occasionally. Breed health surveys and veterinary cardiology clinic reports suggest that a few percent of Golden Retrievers may have some form of congenital heart defect (with SAS being the lion's share of those cases). By contrast, many more Golden puppies might have a murmur at some age that turns out not to be pathological.

**Timing and Variability in Murmur Detection:** Not all murmurs in puppies are evident right away from birth, and conversely, a normal exam at one point doesn't guarantee a murmur won't appear a little later. There is natural variability in when murmurs become audible:

- Innocent physiologic murmurs often become detectable around 6 to 8 weeks of age. A puppy may have a quiet chest at 2 weeks old, but by its first vet check after weaning (around 7–8 weeks) a soft murmur might be heard. This is thought to coincide with changes in the puppy's blood (for instance, a slight anemia that young puppies normally experience, and the fact that their cardiac output increases as they become more active). These murmurs tend to be transient and vanish by 4–5 months old as the cardiovascular system matures.
- Congenital defect murmurs have their own timelines depending on the condition. Some defects cause murmurs that are audible immediately in the neonatal period. For example, a large ventricular septal defect (VSD) or a moderate-to-severe pulmonic stenosis can produce a noticeable murmur in a very young pup (even a few days or weeks old). Patent ductus arteriosus (PDA), another congenital condition, produces a distinctive continuous murmur that can be heard as soon as the puppy is born because of the abnormal vessel flow that starts right after birth. On the other hand, subvalvular aortic stenosis (SAS) often behaves somewhat differently: a mild SAS lesion might not generate much turbulence (and thus little to no murmur) at 6-8 weeks, but as the puppy grows over the next few months, the narrowing can worsen and the murmur can

become evident later. In some Golden Retriever puppies with mild SAS, a veterinarian might not hear anything unusual at the 8-week exam, but by the time the pup is 3–4 months or older, a murmur appears as the obstruction in the heart's outflow tract becomes more pronounced. This progressive nature of SAS is well documented – the fibrous ridge below the aortic valve tends to build up over time, meaning the murmur often grows from nonexistent or very faint early on to more pronounced by young adulthood.

• Dynamic changes and intermittent murmurs: Puppies are wiggly, excitable creatures, and their heart rates and blood flow can change rapidly with activity or stress. An interesting aspect of some innocent murmurs is that they can be "dynamic" – their intensity might increase when the puppy is excited or crying and decrease when the puppy is calm or sleeping. A murmur might even come and go between different veterinary visits, especially if it was borderline to begin with. For instance, a vet might hear a faint murmur at one appointment and then not detect it a couple of weeks later if the puppy's conditions have changed (perhaps the puppy was quieter or the murmur truly diminished). This variability can sometimes cause confusion or false alarms. A conscientious approach is often to perform multiple auscultations over time to see if a murmur persists, intensifies, or disappears.

**Physiology and Growth Factors:** Part of why timing and audibility vary is due to the puppy's physiology and development:

- **Chest conformation and size:** Newborn puppies have a very small chest cavity, and as they grow, the position of the heart relative to the chest wall changes. Initially, heart sounds might be harder to localize, and as ribs grow, the acoustic characteristics shift. A very tiny murmur might not be heard in a tiny puppy but becomes audible when the puppy gets a bit larger.
- **Heart rate:** Puppies have high heart rates, which can make short murmurs harder to hear or differentiate because everything is happening so fast. As the heart rate slows slightly with maturity, a murmur may become more discernible in timing.
- **Exam conditions:** A quiet environment and a calm puppy are essential for accurate detection. If a puppy is panting or crying during an exam, mild murmurs might be masked by the noise of breathing or rapid heart sounds. This is why veterinarians sometimes ask to recheck a puppy when it is more settled, or even after a short play period to tire it out slightly (resulting in quieter breathing).
- **Progression of congenital lesions:** As mentioned, some congenital anomalies worsen or evolve with time (SAS being a prime example). Another example is

certain valve dysplasias: a valve that is mildly malformed at birth might leak more as the heart grows and stretches the valve's attachments, thus a murmur from valve regurgitation could become more pronounced after a few months of growth.

**Diagnostic Nuances:** From a diagnostic standpoint, recognizing this timing and variability is crucial. Veterinarians have to decide, based on the puppy's age and the murmur's characteristics, whether to:

- Monitor and re-evaluate later (common for very young puppies with soft murmurs, giving time to see if it resolves naturally).
- Investigate immediately with advanced diagnostics (if the murmur's nature suggests a likely serious defect).

This decision-making is an art and science; it involves understanding that an early recheck at, say, 12 or 16 weeks can be very informative. If a murmur that was present at 8 weeks is gone by 16 weeks and the puppy is thriving, it likely was an innocent murmur. If it's gotten louder, it could indicate an emerging problem that merits further testing. In contrast, if a usually suspicious type of murmur (for example, a continuous murmur or a loud diastolic murmur) is heard even in a young puppy, a veterinarian will likely not wait and will suggest immediate steps because those are rarely benign.

In Golden Retriever puppies specifically, epidemiological insight tells us to be both watchful and cautious: watchful, because a notable percentage of puppies will have murmurs that ultimately mean nothing serious (so we must avoid knee-jerk alarm and perhaps re-check after some weeks); and cautious, because this breed's predisposition to SAS means that a murmur could be an early sign of something we want to catch sooner rather than later.

Next, we will focus on the "innocent" or "physiologic" murmurs in puppies – those common murmurs which, despite causing concern at first, are actually part of normal puppy development and carry a good prognosis.

# Innocent (Physiologic) Murmurs in Puppies – Etiology, Characteristics, and Prognosis

Not every murmur is a cause for panic. **Innocent murmurs**, also known as **physiologic murmurs**, are benign heart murmurs that occur in an otherwise healthy heart. In puppies, these murmurs are frequently encountered and are considered a normal byproduct of a young growing body. It's analogous to how many healthy human babies and children can have murmurs that they eventually outgrow. In this section, we will explain why these murmurs happen, how to recognize them, and what their outcome typically is.

**Etiology (Causes) of Innocent Murmurs:** The exact cause of innocent murmurs in puppies is not due to a structural defect in the heart, but rather due to the physiology of a puppy's cardiovascular system. Several factors are thought to contribute:

- **High Cardiac Output:** Puppies have a relatively higher cardiac output (the volume of blood the heart pumps) relative to their body size, especially during growth spurts. Their hearts may be pumping very vigorously to support rapid growth and playful activity. When a large volume of blood is pushed quickly through the great vessels (like the aorta or pulmonary artery), a bit of turbulence can occur simply because of the force of flow.
- **Proportionally Small Great Vessels:** One theory is that in young animals, the diameter of the major blood vessels (and outflow tracts from the heart) is a bit small relative to the amount of blood being pumped. Think of water through a narrow hose even if the hose is normal, pushing a lot of water through quickly can create noise. As the puppy grows, the vessels widen and accommodate flow more silently.
- **Blood Viscosity and Mild Anemia:** Puppies naturally undergo a developmental phenomenon sometimes called "physiologic anemia of youth." When puppies transition from nursing to solid food and grow rapidly, there can be a slight dip in red blood cell concentration for a short period. Thinner blood (lower viscosity) flows more readily and can be more prone to turbulence, much like how thinner fluids create more splashing. This mild anemia, combined with high output, is thought to contribute to the presence of murmurs in a significant number of healthy pups. As their red blood cell count normalizes in a few months, the murmurs often fade.
- **Sympathetic Tone and Excitement:** Puppies can have fluctuating adrenaline levels when they are excited or scared at the vet, their heart beats stronger and faster. This can transiently create or amplify a murmur that wouldn't be as noticeable when the puppy is calm. In other words, some innocent murmurs are dynamic: a playful romp or a bit of anxiety could bring out the murmur sound, which might almost vanish when the pup is resting.

It's important to note what is *not* the cause in these cases: there is no structural malformation like a hole or tight valve. The heart anatomy is normal for the puppy's age.

**Grading and Characteristics:** Innocent murmurs have fairly consistent characteristics that veterinarians recognize:

• They are **low in intensity** – typically graded I or II out of VI (see Part V for grading scale details). This means they are soft sounds. A Grade I murmur is so

faint it's barely discernible and often comes and goes, while Grade II is still a low-volume murmur that is heard easily but is still a quiet whoosh.

- They occur **during systole** (when the heart contracts). Innocent murmurs in puppies are short, systolic murmurs that occur just after the "lub" and end before the "dub." They do not continue through the whole heartbeat, and they are not present during diastole.
- The point of maximal intensity (PMI) of innocent murmurs is usually on the left side of the chest, near the base of the heart (around the area of the pulmonary or aortic valve outflow). Often, the murmur is best heard in the left second to fourth intercostal space near the sternum. It's sometimes called a "left basilar murmur." You typically will not hear an innocent murmur loudest on the right side of the chest a right-sided murmur in a puppy suggests a different issue, not a physiologic murmur.
- Innocent murmurs have a blowing, whooshing, or musical quality but are not harsh. Sometimes veterinarians describe them as "vibrant," "wispy," or even "whistling." Because they are generated by smooth structures (no irregular valve or hole edges), the sound tends to be more uniform or "tonal" (hence the description "musical" murmur is sometimes used).
- They **do not radiate far**. A strong pathological murmur can often be heard in multiple locations or even with a hand on the chest (a thrill). Innocent murmurs are localized; you usually have to listen in just the right spot over the heart to catch it, and it's not felt as a vibration on the chest wall.
- They are often **variable with position or excitement**. The murmur might be evident when the puppy is standing or sitting, but if the puppy lies down calmly, it might diminish. These murmurs can also become louder temporarily if the puppy's heart rate increases (like during play or agitation).

Locations and How They Differ from Pathologic Murmurs: To give context, a veterinarian will listen at specific "listening posts" on a dog's chest. An innocent murmur in a Golden puppy will typically be caught on the left side near the heart base. In contrast, if a murmur were loudest near the left lower side (apex) or on the right side, the vet's suspicion would shift to other causes (for example, a right-side murmur might point to a VSD or tricuspid valve issue rather than an innocent flow murmur). Thus, the typical location of an innocent murmur helps distinguish it.

**Timeline and Resolution:** One of the hallmark features of innocent murmurs in puppies is that they are **transient**. They generally appear in the first couple of months of life and resolve on their own a few weeks to a few months later. Most innocent murmurs will

disappear by about 4 to 5 months of age, and almost all are gone by 6 months. As the puppy grows:

- The heart and vessels mature, reducing turbulence.
- The blood viscosity returns to normal.
- If any small differences in flow dynamics were present, the growing heart corrects them.

For example, a Golden Retriever pup that had a soft Grade I-II murmur at its 8-week check might show no murmur at the 16-week vaccination visit. This is a classic innocent murmur scenario. The puppy remains active, gains weight, shows no breathing issues or any other sign of illness during that time – all of which supports that it was a benign murmur.

It's worth noting that some physiologic murmurs can persist a bit longer in certain individuals or breeds, but they remain quiet and without clinical significance. Occasionally, a dog might even carry a very soft innocent murmur into adulthood (some adult dogs have murmurs with absolutely no heart disease – just unique physiology). Among Boxers, for example, research showed many healthy individuals had murmurs persist beyond puppyhood. But in the majority of cases with Golden Retrievers and similar breeds, the murmurs go away as the pup passes the 6-month mark.

**Prognosis for Innocent Murmurs:** The great news about innocent murmurs is that they are "innocent" in every sense – they do not affect the puppy's health or lifespan at all. They require no treatment, only observation to ensure they do resolve and nothing changes for the worse. Puppies with innocent murmurs eat, play, and grow normally. There are no restrictions needed on their activity. Families should, however, maintain regular veterinary check-ups to verify that the murmur has disappeared and that no other signs of heart problems develop. Essentially, the approach is one of watchful reassurance: we keep an ear on it, but we expect the puppy to outgrow the murmur with time.

Veterinarians often will educate owners that an innocent murmur is like a "normal murmur" of puppyhood – an interesting observation but not a disease. Once the murmur has resolved and the heart is confirmed healthy, it's as if it was never there. The puppy can go on to live a full, active life with no cardiac issues from that murmur.

**Distinguishing Innocent from Pathologic:** Because innocent murmurs can sound mild and some mild congenital heart defects can also produce only mild murmurs, distinguishing the two can be challenging initially. A very soft murmur could, in rare cases, be the early hint of a problem like mild subaortic stenosis. This is why if any

doubt exists, a veterinarian might recommend further examination or a repeat exam later. There are a few guidelines that help:

- Murmurs that are grade III or louder in a young puppy are less likely to be innocent and deserve prompt evaluation.
- Murmurs that persist beyond six months of age should be investigated if they haven't been already.
- If a murmur has an atypical location (for example, loudest on the right side or very far forward towards the neck) or if it is continuous (heard throughout the heartbeat), it is not consistent with an innocent murmur.
- The overall health of the puppy matters: a puppy with just a murmur and no other symptoms is more reassuring than one that's also undersized for its age, breathing hard, or exercise intolerant (the latter scenario suggests the murmur is a symptom of a larger problem).

To conclude this section, innocent murmurs are essentially a quirk of the developing heart – extremely common and usually nothing to worry about. A Golden Retriever puppy with an innocent murmur will generally outgrow it with no residual effects. However, the key lies in proper identification and follow-up. Owners are encouraged to follow their vet's advice for re-examination to ensure the murmur indeed disappears. With innocent murmurs explained, we now turn to the other side of the coin: **pathologic murmurs**, which are those associated with congenital heart conditions that puppies can be born with.

# Pathologic Murmurs and Congenital Cardiac Conditions in Golden Retriever Puppies

While many murmurs in puppies are harmless, some murmurs are "pathologic," meaning they result from an underlying abnormality in the heart. Congenital (present at birth) cardiac conditions can cause such murmurs. In Golden Retrievers, we pay special attention to pathologic murmurs because, as mentioned, this breed can inherit serious heart defects like subvalvular aortic stenosis (SAS). In this section, we'll outline the major congenital heart diseases that can cause murmurs in Golden Retriever puppies, focusing on SAS and tricuspid valve dysplasia (TVD) as requested, and also covering others such as pulmonic stenosis, ventricular septal defects, and more. We will describe each condition briefly, including what it is, how it causes a murmur, typical murmur characteristics, and any unique aspects. Finally, we'll touch on extracardiac (outside the heart) reasons for murmurs, which while not common, are important to recognize.

**Overview of Congenital Heart Defects:** Congenital heart defects (CHDs) in dogs can be categorized into a few broad types:

- **Outflow Obstructions:** Narrowing in the paths where blood exits the heart. This includes subvalvular aortic stenosis (narrowing below the aortic valve) and pulmonic stenosis (narrowing at the pulmonic valve). These cause the heart to push blood through a smaller opening, leading to turbulence and often a classic murmur.
- Valve Dysplasias (malformations): Valves that are malformed and often leaky (regurgitant) or occasionally narrowed (stenotic). In Goldens, tricuspid valve dysplasia is one example (malformed tricuspid valve causing leakage from the right ventricle back into the right atrium during systole). Mitral valve dysplasia is another type seen in some breeds (e.g., Bull Terriers, Great Danes), though it's not a common Golden Retriever issue.
- Shunts (abnormal blood flow connections): Holes or vessels that shouldn't be open after birth but are, causing blood to go in abnormal directions. Examples: ventricular septal defect (a hole in the wall between left and right ventricles), atrial septal defect (hole between atria), and patent ductus arteriosus (a fetal blood vessel that remains open after birth, connecting aorta and pulmonary artery).
- **Complex Defects:** Combinations of the above or more complex structural issues (like Tetralogy of Fallot, which is a combination of a VSD, pulmonic stenosis, and other changes, leading to right-to-left shunting and cyanosis). These are rarer and often cause severe clinical signs early on.

Golden Retrievers are predominantly plagued by SAS in terms of congenital issues. They are not especially known for high rates of other specific defects, but any individual Golden could have any of these by chance. Let's go through the key conditions:

# Subvalvular Aortic Stenosis (SAS)

What it is: SAS is a congenital narrowing just below the aortic valve in the left ventricle's outflow tract. Think of it as a ridge or ring of fibrous tissue that partially blocks the exit of blood from the heart's left ventricle as it goes into the aorta. Because the obstruction is below the aortic valve, the valve itself is usually normal; the problem is the abnormal tissue buildup in the ventricle outflow area. SAS is often described in grades of severity (sometimes called grades I, II, III or mild, moderate, severe). Mild cases have just a small fibrous bump causing minor obstruction, moderate have a more defined ridge, and severe can have a complete fibrous ring or even a tunnel-like narrowing.

**Breed Predisposition:** SAS is the number one congenital heart disease in Golden Retrievers. It's also common in Newfoundlands, Rottweilers, and some other large breeds. It's inherited (we will discuss genetics in Part VII) and tends to run in certain

families or lines of dogs. So if a Golden puppy is born with SAS, likely it was not a random fluke but a result of genetic predisposition.

**Hemodynamic effect:** Because of the narrowing, the left ventricle must generate higher pressure to push blood through the small opening into the aorta. This pressure overload causes the ventricle muscle to thicken over time (**concentric hypertrophy**). The blood that does make it through shoots out at high velocity, creating turbulence in the aorta – hence the murmur. The turbulence can also cause a bit of trauma to the aortic valve or wall over time, sometimes leading to aortic valve leakage (regurgitation) or dilation of the aorta after the narrowed point.

**Murmur characteristics:** SAS typically produces a **systolic ejection murmur**. It is often described as a crescendo-decrescendo ("diamond-shaped") murmur, meaning it starts softer, rises to a peak intensity, and then falls off, all during systole. The murmur is **loudest at the left heart base**, roughly in the area of the aortic valve (4th intercostal space just below the shoulder). It often radiates – you might hear it on the right side too, or even up toward the throat. In fact, in some cases, you can feel a thrill (vibration) over the heart base or even in the carotid artery area in the neck of the dog if the murmur is strong. The intensity of the murmur can range from very faint in mild SAS to extremely loud (Grade V/VI or even VI/VI with a thrill) in severe SAS. However, as noted before, a mild SAS might sometimes produce no audible murmur in a tiny puppy and only a faint one later, whereas severe SAS tends to be evident early with a loud murmur.

**Symptoms and significance:** Puppies with mild SAS often show no outward symptoms at all and may live a normal life, though they carry the defect. Moderate to severe SAS can start to cause clinical signs as the dog grows: exercise intolerance (the puppy or young dog may tire easily or not keep up with playmates), fainting spells (syncope, especially during excitement or exercise, due to not enough blood getting out or due to arrhythmias triggered by the strain on the heart), or in worst cases, sudden collapse and death due to heart rhythm disturbances. Because signs might not appear until later, an 8-week-old SAS puppy might seem completely fine outwardly. This is why the murmur detection is so important – it's often the only clue until something dire happens. Sadly, SAS is known to be a cause of unexpected sudden death in young Golden Retrievers who were previously thought healthy; usually these are the severe cases that went unnoticed or were not recognized in time.

**Management:** While this section is mostly about recognition, it's worth noting how SAS is handled: There is no simple surgical fix for SAS like there is for some other defects. Balloon dilation (a catheter procedure to stretch open the narrowing) has been tried but with limited success, because the fibrous ridge tends to recur and the risk of serious complications is high. Instead, management often involves medications like beta-blockers to reduce the heart's oxygen demand and help stabilize heart rhythm, and

exercise restrictions for dogs with moderate to severe SAS to prevent overexertion. Severe SAS significantly shortens lifespan (many severe cases might only live a few years, maybe up to middle age at best). Mild cases often have normal lifespans but should not be bred. For a family with a Golden Retriever diagnosed with SAS, careful long-term veterinary cardiology follow-up is needed.

**Prognosis in puppies:** If a Golden puppy is confirmed to have SAS (say via an echocardiogram at a young age), the prognosis will depend on severity. Mild cases can be quite compatible with a normal life; the dog might just take daily medicine and avoid extreme exertion. Severe cases carry a guarded prognosis and the risk of sudden loss. Knowing this early allows owners and vets to take precautions and manage the condition proactively, though it can be heartbreaking news to receive.

# Tricuspid Valve Dysplasia (TVD)

What it is: Tricuspid valve dysplasia is a congenital malformation of the tricuspid valve – the valve between the right atrium and right ventricle. In TVD, the valve's leaflets, chordae tendineae (the "strings" that anchor the valve), or papillary muscles can be abnormally formed. The result is usually that the valve does not close tightly (some portion of it is misshapen or "floppy"), causing blood to leak backward from the right ventricle to the right atrium every time the heart contracts. In some cases, the valve may also be positioned incorrectly (for example, an Ebstein's anomaly in human terms – where the valve is set low in the ventricle). TVD is the most common congenital heart defect in some breeds like Labrador Retrievers and certain giant breeds like the Dogue de Bordeaux. It's less common overall than SAS in the general dog population, but it certainly can appear in Golden Retrievers as well (especially if somewhere in their lineage this trait was present or if by random chance).

**How it causes a murmur:** A dysplastic tricuspid valve that is regurgitant will cause a **holosystolic murmur** (meaning it spans the entire systole from S1 to S2) because as soon as the ventricle contracts, blood is leaking backward the whole time. This murmur is best heard at the **right side of the chest, near the lower heart (right apical area)** where the tricuspid valve is located. It often has a "plateau" quality (more constant intensity throughout systole, as opposed to the crescendo-decrescendo of SAS) and is typically described as a **blowing murmur** since valvular regurgitation tends to sound more like a whooshing blow rather than an ejection "rush." In moderate or severe TVD, this murmur can be quite audible even in a young puppy.

**Associated signs:** Because the right side of the heart is affected, severe tricuspid dysplasia can lead to right atrium enlargement (since blood keeps flowing back into the atrium under pressure). The increased pressure in the atrium can back up into the venous system, potentially causing liver enlargement or fluid buildup in the abdomen (ascites) in a puppy – signs of right-sided congestive heart failure. However, mild cases

might show no such signs, just a murmur. A very severe TVD, paradoxically, might sometimes produce a quieter murmur than expected; if the valve is extremely malformed, sometimes the forward output of the right heart is reduced (less blood flow overall might result in less turbulence noise, even though the heart is quite compromised). So generally, moderate cases tend to have the loudest murmurs.

**Golden Retriever context:** Golden Retrievers aren't as notorious for TVD as Labradors are, but it's worth highlighting because it does occur and a breeder specifically concerned with heart murmurs would want to know about it. If a Golden puppy has a distinctly right-sided murmur, one of the differential diagnoses the vet will consider is tricuspid valve dysplasia. This is particularly true if SAS (left side murmur) has been ruled out or the murmur's location doesn't fit SAS or VSD. In breeding circles, if TVD is identified in a Golden, it would raise concerns about a genetic component—some cases might represent a new mutation or an inherited trait from a distant relative (given Goldens and Labradors share some ancestry if you go back far enough, it's not impossible for the gene pool to carry similar issues).

**Management:** There is no surgical fix for TVD in dogs; treatment focuses on managing any heart failure symptoms if they arise (like diuretics for fluid, and ACE-inhibitors or other drugs to reduce the volume load). Many dogs with mild TVD live for years without needing any specific meds. Breeding-wise, an affected dog should not be bred.

**Prognosis:** It really varies with severity. Mild TVD – a dog can be asymptomatic and just have a murmur for life, possibly living a full lifespan. Severe TVD – the dog might develop heart failure at a young age. For a puppy buyer or owner, finding out about TVD would mean needing to partner with a cardiologist to gauge how severe it is and what to expect.

# Pulmonic Stenosis (PS)

**What it is:** Pulmonic stenosis is a congenital narrowing of the outflow from the right ventricle into the pulmonary artery (leading to the lungs). Often, it is a malformation of the pulmonic valve itself (thickened valve leaflets, or they are partially fused so the valve doesn't open wide). Less commonly, the narrowing can be just below or above the valve. The effect is that the right ventricle faces an obstruction when pumping blood to the lungs.

**Murmur characteristics:** PS causes a **systolic ejection murmur**, much like SAS but on the other side. It is loudest at the **left base of the heart**, typically a bit more forward (toward the puppy's head) and slightly lower than the aortic area – usually the left 3rd intercostal space near the costochondral junction. Veterinarians often say "left basilar murmur" for both PS and SAS; they can sound very similar by ear, though sometimes PS murmurs might be even harsher in quality. The murmur from a significant pulmonic stenosis can be very loud and also radiate. You might also detect a palpable thrill over the left cranial chest in a severe case. Because PS increases the workload on the right ventricle, over time it causes thickening of the right ventricle muscle.

**Breed predisposition and Golden Retrievers:** Pulmonic stenosis is quite common in certain breeds like Bulldogs, Beagles, and smaller breeds such as terriers and spaniels. It's actually one of the most common heart defects in dogs overall. Golden Retrievers are not a high-risk breed for PS specifically, but it can and does occur sporadically in the breed. Thus, if a Golden puppy has a left-base systolic murmur, a cardiologist might differentiate SAS vs PS by echo (because on auscultation alone it might not be obvious which one it is). In general, if we hear "left base murmur in a Golden," SAS would be our first thought due to breed likelihood, but PS should not be assumed impossible.

**Symptoms:** A pup with moderate to severe PS might show signs like exercise intolerance or fainting (similar to SAS but due to right heart output limitation). In severe cases, right-sided heart failure signs (ascites, jugular vein distension) can occur, or even cyanosis if there's a complication like a PFO (patent foramen ovale) causing mixing of blood due to high right-side pressures.

**Treatment:** The good news with pulmonic stenosis is that there is an effective intervention for many cases: balloon valvuloplasty. This is a catheter-based procedure where a balloon is inflated at the site of narrowing to widen it. In many breeds and cases, this greatly improves outcome, especially if done early for severe PS. If intervention isn't done, dogs with severe PS might eventually succumb to heart failure or arrhythmias.

**Prognosis:** Mild PS often has minimal impact; severe PS, if untreated, can shorten lifespan. But with successful ballooning, a puppy could potentially live a normal or near-normal life.

# Ventricular Septal Defect (VSD)

**What it is:** A ventricular septal defect is a hole in the wall (septum) separating the left and right ventricles. It's essentially a "shunt" that allows blood to flow from the left ventricle (higher pressure) to the right ventricle (lower pressure) during systole. VSDs can vary in size from tiny pinholes to very large openings.

**Murmur characteristics:** VSDs typically produce a **holosystolic murmur** (much like valve regurgitations do) because as soon as the ventricles contract, blood is shunting through the defect throughout the entire systolic phase. The murmur from a classic VSD in a dog is usually best heard on the **right side of the chest** along the sternal border (around the right 4th intercostal space near the sternum). It often has a high-pitched or harsh quality, especially if the defect is small. Interestingly, the smaller the hole (to a point), the louder and higher-pitched the murmur tends to be, because a small hole

causes a very high velocity jet of blood – think of pinching a hose to spray water faster. Conversely, a very large VSD might actually produce a less intense murmur (or sometimes a different sounding murmur) because the pressure between the two ventricles equalizes and there's less turbulent jet; however, large VSDs cause more severe physiological problems even if the murmur is not as loud.

**Associated effects:** A moderate or large VSD means a lot of blood from the left ventricle is being wasted by recirculating into the right ventricle and to the lungs. This volume overloads the pulmonary circulation and left side of the heart (since blood goes to lungs then back to left atrium and ventricle repeatedly). Over time this can cause left side heart enlargement and congestive heart failure (pulmonary edema). Very large VSDs in puppies can lead to heart failure signs within months if not addressed, or they may lead to a phenomenon called Eisenmenger's syndrome if they are so large that pressures equalize or flip (this is when the shunt reverses direction and causes deoxygenated blood to bypass the lungs – rare in puppies because many don't survive to that stage without intervention).

**Golden Retriever context:** Goldens do not have a particular predilection for VSDs; these defects occur randomly across many breeds. If a Golden puppy did have a significant VSD, it would be a bit of a rare scenario. But a vet hearing a right-sided murmur would include VSD in the differential diagnosis. Often, small VSDs are incidental findings (a pup has a loud murmur but is growing well, echo finds a tiny VSD that may even close on its own or remain small without issue). Large VSDs are a serious congenital defect needing intervention.

**Treatment:** In dogs, treating a VSD can be complex. Some small animal surgical centers have attempted device closures or open-heart surgery to patch VSDs, but these are high-risk and not commonly done. More often, if the VSD is moderate to large, medical management of heart failure is used and sometimes an owner may opt for a high-risk surgical fix if it's feasible. Small VSDs just require monitoring – often no intervention is needed as the dog can live normally if the defect doesn't significantly strain the heart.

**Prognosis:** Small VSD – excellent (the dog might live normally, possibly with a murmur for life but no issues). Large VSD – guarded to poor without advanced intervention (which itself is risky). Many pups with very large VSDs unfortunately may not survive long if heart failure cannot be controlled, or they may be euthanized if quality of life is poor early on. Each case is individual.

#### Other Conditions (including PDA and ASD)

Although not explicitly listed in the question, for completeness:

- Patent Ductus Arteriosus (PDA): This is a condition where a fetal blood vessel (the ductus arteriosus) fails to close after birth. The ductus connects the pulmonary artery to the aorta during fetal life (bypassing the lungs). If it stays open, blood from the aorta flows back into the pulmonary artery continuously. PDA produces a classic continuous murmur, often described as a "machinery" murmur because it is heard throughout systole and diastole without a pause, usually loudest at the left base. Golden Retrievers are not particularly predisposed to PDA (it's often seen in breeds like Poodles, Pomeranians, Shelties, etc., often female pups), but it can occur in any breed. PDAs are significant because they cause excessive blood flow to the lungs and can lead to heart failure if not corrected. The good news is PDAs are very treatable typically corrected with surgery or a minimally invasive device occlusion. If a Golden puppy had a continuous murmur, a vet would be immediately thinking of PDA as a likely cause, since few other conditions cause continuous murmurs.
- Atrial Septal Defect (ASD): A hole between the atria. Isolated ASDs are relatively uncommon in dogs. Small ASDs often don't cause a loud murmur at all; they might cause a subtle widening of the second heart sound or a very quiet flow murmur at the pulmonary area because of increased right-side flow. Large ASDs can cause overload of the right side and some murmurs, but usually if a vet hears a prominent murmur in a puppy, an ASD is not the top suspicion because the murmur of ASD is often subtle. ASDs might be found incidentally on echo if a murmur leads to an exam, or if the dog later shows signs like exercise intolerance. In Golden Retrievers, ASDs are rare enough that they aren't a primary focus.
- **Tetralogy of Fallot (TOF):** This is a combination of VSD, pulmonic stenosis, a shift in the aortic position, and right ventricle hypertrophy. It's a cyanotic heart defect (meaning it causes low oxygen in the blood, so puppies often show blue-tinged gums or tire very quickly). It would cause a murmur (largely due to the pulmonic stenosis and VSD), but these pups are typically very ill early on, and thankfully it's rare in Goldens (more common in some terriers and Keeshonds by breed predisposition).
- Mitral Valve Dysplasia (MVD): Not asked for, but just to parallel TVD: a
  malformed mitral valve on the left side. It would cause a left-sided holosystolic
  apical murmur (like chronic mitral regurg in older dogs). Goldens are not known
  for MVD as a common issue (Bull Terriers are one breed with that predisposition).
  A severe MVD puppy would be in left-sided heart failure early (pulmonary
  edema). It's pretty uncommon in Goldens.

**Extracardiac Causes of Murmurs:** Lastly, we consider **extracardiac** causes – meaning the heart is structurally normal, but factors outside the heart cause turbulent flow. These are not congenital heart diseases, but they can create murmurs and thus come into the diagnostic picture:

- Anemia: As mentioned earlier, severe anemia (very low red blood cell count) can cause a functional murmur. In puppies, heavy infestations of parasites (like fleas causing blood loss, or hookworm infections causing intestinal bleeding) can lead to anemia. An anemic puppy often has pale gums and may be weak. The murmur comes from the blood being less viscous and the heart pushing a higher volume to deliver enough oxygen, causing a swishing noise. If a murmur is heard in a weak, pale puppy, a vet will also check for anemia via blood tests.
- Fever or Hyperthyroidism: Any condition that greatly increases heart rate and output (such as a high fever or, in older animals, an overactive thyroid gland) can produce a temporary murmur due to the hyperdynamic circulation. In a young puppy, fever from infection could transiently cause or exacerbate a murmur sound. Of course, the primary issue is treating the underlying cause (infection, etc.) and then the murmur typically resolves.
- **Hypoproteinemia (low blood protein):** Similar to anemia, if a puppy has very low protein levels in blood (perhaps due to malnutrition or intestinal disease), the blood is thinner and can cause murmurs.
- Athletic heart syndrome (high vagal tone): More applicable to older animals or specific cases, but some very fit young dogs might have murmurs due to the way their heart pumps strongly at rest. Not really an "extracardiac pathology," just a physiologic variation.

In Golden Retriever puppies, extrinsic causes like anemia are relatively rare in wellcared-for litters, but a rescue puppy or one with heavy parasites might indeed have a murmur that disappears after deworming and nutritional support.

**Summarizing Pathologic Murmurs:** A murmur that is pathologic in a puppy typically has one or more of these red flags: it is louder (grade III or above), persists or worsens as the puppy grows, has an unusual timing (like continuous or diastolic), or the puppy has other symptoms. For Golden Retrievers, SAS is the big one to watch for (left basilar systolic murmur, often grade II or higher, usually noticed by a few months old at the latest for significant cases). TVD would present a right-sided murmur from the start if present. PS and VSD likewise usually present early with murmurs if moderate to severe. Each of these conditions requires veterinary follow-up, often with a specialist, and often some degree of intervention or at least life-long management. Unlike innocent murmurs,

pathologic murmurs will not go away on their own – they are a sign of an underlying defect that will persist (and could progress).

As we recognize that a murmur might be pathologic, the next step is figuring out exactly what is causing it and how severe it is. This brings us to the diagnostic process.

# Veterinary Diagnostic Process for Murmurs – From Stethoscope to Echocardiography

When a heart murmur is detected in a Golden Retriever puppy (or any pet), veterinarians follow a systematic diagnostic process to determine the cause and significance of that murmur. In this section, we'll walk through how veterinarians approach heart murmurs: the art of **auscultation** (listening with a stethoscope), how murmurs are classified and described, what clues suggest a murmur is benign versus concerning, and the role of advanced diagnostics like consultation with a veterinary cardiologist and **echocardiography (heart ultrasound)** with Doppler to visualize the heart's structure and blood flow. By understanding this process, families can appreciate why a vet might recommend a wait-and-see recheck or, alternatively, immediate imaging, and what the steps mean for the puppy's care.

**Auscultation Techniques:** The very first tool in evaluating a murmur is the stethoscope. Auscultation is more than just "hearing" a murmur – it's a skilled examination that veterinarians practice to pick up subtle details. Key aspects include:

- **Environment:** The exam should ideally be in a quiet room. If a puppy is crying or panting, the vet might try to calm the puppy or even hold the muzzle gently closed for a moment to listen between breaths. Excess noise can obscure the heart sounds.
- **Positioning:** The vet will listen on both sides of the chest, as well as along the sternum. Typically, they listen in at least four spots (each corresponding roughly to one of the heart valves: pulmonary, aortic, mitral on the left side, and tricuspid on the right side). In a squirmy puppy, this may be done quickly in succession, but an experienced vet will often repeat and reposition to ensure they identify the point of maximal intensity of any murmur.
- **Multiple times or moments:** Sometimes the vet will listen, then let the puppy relax or walk around, then listen again. If a murmur was borderline, maybe a second listen confirms it. If the puppy's heart rate was very fast the first time, a second listen when it's calmer might clarify the timing of the murmur.

**Murmur Classification:** Once a murmur is detected, vets characterize it with several descriptors:

• Grade (Intensity): Murmur intensity is graded on a scale of I to VI (1 to 6).

- Grade I: Extremely faint, heard only in ideal conditions and maybe only intermittently.
- o Grade II: Soft, but definitely heard once you're tuned in.
- Grade III: Moderate intensity, immediately audible, but no thrill (no vibration felt).
- Grade IV: Loud murmur, heard widely over the chest, possibly with a thrill.
- Grade V: Very loud, with a palpable thrill (one can feel a buzzing on the chest wall).
- Grade VI: Exceptionally loud, audible even if the stethoscope is lifted slightly off the chest, with a thrill.
   Most puppy innocent murmurs are Grade I-II, occasionally maybe a III at their peak when excited. Pathologic murmurs can be any grade depending on severity of the lesion and even mild lesions can have lower grades that overlap with innocent ones, which is why other features are needed to differentiate.
- **Timing:** The vet notes when in the cardiac cycle the murmur occurs.
  - Systolic murmurs are heard between the first and second heart sounds (between "lub" and "dub"). The vast majority of murmurs in puppies are systolic (innocent murmurs, SAS, PS, VSD, MR, TR all cause systolic murmurs).
  - Diastolic murmurs occur after the "dub," during the heart's relaxation and filling phase. These are uncommon in puppies; an example would be a diastolic murmur from aortic insufficiency if SAS is so severe it causes leaking, or from pulmonic insufficiency or rarely a mitral stenosis (extremely rare congenital issue in dogs). If a vet hears a diastolic murmur, that is usually a clear indication of pathology and triggers immediate further exam.
  - Continuous murmurs start in systole and continue through the second sound into diastole without stopping. The classic cause is a PDA.
     Continuous murmurs are unmistakable in significance – a vet will assume congenital defect (likely PDA) and move to confirm it.
  - Additionally, the vet may describe the shape: for instance "holosystolic" (throughout systole), "early systolic," or "late systolic," etc., and mention things like "crescendo-decrescendo" (for ejection murmurs like SAS/PS) or "plateau" (for regurgitant murmurs like VSD or valve dysplasias).

- Location (Point of Maximal Intensity): This means where on the chest the murmur is heard the loudest.
  - Left base (upper left) common for SAS and PS and innocent murmurs.
  - Left apex (lower left) typical for mitral regurgitation (unlikely in a puppy unless MVD).
  - Right side typical for tricuspid regurgitation or VSD.
  - Sternal border sometimes used to indicate a murmur heard best along the bottom of the chest; VSD murmurs often are along the right sternal border.
  - The vet might note, for example, "Grade II/VI left basilar systolic murmur" which in a Golden puppy might suggest an innocent flow murmur or mild SAS. Or "Grade IV/VI holosystolic right apical murmur with a thrill" which would strongly point to something like tricuspid valve dysplasia.
- **Radiation:** Does the sound radiate or transmit anywhere else? Murmurs from semilunar valve stenoses (like SAS and PS) often radiate up toward the thoracic inlet (base of neck) because the flow turbulence is in the great vessels. Murmurs like VSD can radiate across to the opposite side of the sternum. In a clinical exam note, a vet might mention if they can also hear it on the right side or if a thrill is felt at the thoracic inlet.
- **Pitch/Quality:** Some vets note if a murmur is "harsh," "musical," "blowing," "highpitched" etc. This can give clues – a musical or vibratory murmur in a tiny puppy often is innocent, whereas a harsh one might indicate a significant turbulence like a small VSD or a severe outflow obstruction.

**Indicators of Pathology vs Innocence during Exam:** During this initial auscultation, the veterinarian is essentially triaging the murmur:

- If it's a very soft murmur in a puppy younger than 4 months, the puppy is otherwise completely healthy, and the murmur has the typical features of an innocent murmur (left basilar, systolic, grade I-II, no thrill, goes away when puppy is calm, etc.), the vet might lean towards it being physiologic. They may not jump into extensive testing right away but will advise monitoring. Often the plan is to listen again in a few weeks or at the next vaccine visit, or suggest re-evaluation at 4-6 months of age. Many times, these murmurs will be gone by then.
- If the murmur is loud (grade III or higher) or has any unusual characteristics (e.g., right-sided location, very long duration, presence of a thrill), or if the puppy is older (say 6 months and still has a murmur) or has any symptoms, the

veterinarian will consider it suspicious for a congenital defect. The recommendation in that case would usually be to proceed with further diagnostics sooner rather than later.

- Additionally, if the murmur is continuous or diastolic (which as we said is almost certainly pathologic), that is an immediate red flag requiring advanced diagnostics.
- The vet will also examine for other evidence of heart trouble:
  - Checking the **femoral pulse quality** (for example, if the pulses are very weak or delayed relative to the heartbeat, it might suggest aortic stenosis; if they are bounding, that's often seen with PDA due to wide pulse pressure).
  - Looking at mucous membrane color and capillary refill (are the gums pink, does blood refill quickly? – pale or slow refill might indicate poor output).
  - Feeling the precordial impulse (the heartbeat felt through the chest wall

     a very strong heave might indicate enlarged heart working hard).
  - Checking jugular veins for abnormal pulsation or distension (which can indicate right heart issues).
  - Noting the puppy's respiratory rate and effort (fast breathing or exertion could hint that the heart isn't keeping up, possibly fluid in lungs if left-sided failure).
  - Checking for distended abdomen or fluid (ascites) would indicate right heart failure (which could happen with severe tricuspid dysplasia or severe pulmonic stenosis, even in a pup).

These ancillary findings, combined with the murmur's characteristics, guide the urgency of follow-up.

**Role of Veterinary Cardiologists:** If a murmur is deemed likely pathologic or if there is any ambiguity, a veterinary cardiologist is often consulted. A board-certified cardiologist has specialized training in small animal heart diseases and often more experience in distinguishing subtle murmurs. From a practical standpoint:

• A general practitioner vet might refer the puppy to a cardiologist for an expert auscultation and confirmation of the likely diagnosis. Cardiologists might detect things others can't, and they have the equipment to do a full workup.

 Cardiologists will perform an echocardiogram, which is the gold standard for diagnosing congenital heart defects. Many cardiologists travel with portable ultrasound machines or the puppy is taken to a specialty hospital where these imaging tools are available.

**Echocardiography (Ultrasound of the Heart):** This is a non-invasive test where a probe (transducer) is placed on the puppy's chest (often some fur is shaved to get good contact) and ultrasound waves create an image of the heart in motion. For murmurs, the echo is invaluable:

- 2D Echocardiography: Shows the anatomy of the heart chamber sizes, valve structure, any obvious holes in septa, thickness of heart walls, etc. The cardiologist can directly see, for example, if the tricuspid valve looks abnormal, or if there is a ridge below the aortic valve suggesting SAS, or if the pulmonary valve is thickened and barely opening for PS. They can visualize a PDA ductus if present, or a VSD jet on color Doppler.
- **M-Mode Echocardiography:** This mode measures movements of structures and chamber dimensions more precisely (often used for quantifying function or wall thickness).
- **Color Doppler:** This feature displays blood flow direction and relative velocity by color overlay on the 2D image (blue for flow in one direction, red for the opposite, with mosaic patterns for turbulent flow). It can literally show the jet of abnormal flow through a defect or leaking valve. For example, a VSD will show a jet of blood moving from the left ventricle to right, visualized in color. Regurgitation through the tricuspid or mitral valve is seen as a flash of color going the wrong way in the atrium during systole.
- Spectral Doppler: This is used to measure the velocity of blood flow at specific points. It's crucial for conditions like SAS and PS. The Doppler can measure how fast blood is moving through the outflow. By using the modified Bernoulli equation (which cardiologists do automatically via the machine's software), the pressure gradient caused by the stenosis can be calculated (Pressure gradient = 4 \* velocity^2). So if the Doppler shows a peak velocity of 4 m/s across the aortic outflow, that implies a gradient of 64 mmHg (which is a moderately severe SAS). Mild SAS might have velocities like 2.5-3 m/s (gradient ~25-36 mmHg). This quantification helps stage the severity. Similarly for PS, measuring the gradient across the pulmonic valve dictates whether an intervention is needed.
- **Other info from echo:** The scan will also show if the heart is coping well or not. Are chambers enlarged? Is there evidence of secondary issues (like valve leakage that developed secondary to a defect)? In SAS, is the aortic valve

leaking, is the aorta dilated beyond the stenosis? In tricuspid dysplasia, how enlarged is the right atrium? This all feeds into the prognosis and plan.

For a Golden puppy with a murmur, an echocardiogram is often recommended if the murmur is still present after 4-6 months or earlier if it was suspicious to begin with. Echocardiography is painless and often can be done without heavy sedation in many puppies (sometimes a light sedative is given to help them stay still). The owners can often get immediate answers from this procedure—seeing the heart beating in real time and having the cardiologist point out any defect.

# Additional Diagnostic Tools:

- Electrocardiogram (ECG): This records the electrical activity of the heart. It's not a primary tool for diagnosing the cause of a murmur, but it can show abnormalities like arrhythmias or chamber enlargement patterns which might support a diagnosis. For example, a puppy with significant right heart enlargement from severe PS might have certain changes on ECG. In practice, an ECG is often part of a cardiology workup, but usually echo gives more direct info for congenital issues.
- Chest X-rays (Radiographs): X-rays can show the silhouette of the heart and the pulmonary vasculature. In a tiny puppy, subtle changes might be hard to see, but in older puppies or if heart failure has begun, an X-ray might reveal an enlarged heart or fluid in the lungs. For congenital issues like PDA, an experienced radiologist can sometimes see a characteristic bulge in the aorta on X-ray or a very enlarged left atrium/ventricle. X-rays are helpful to assess if there is any pulmonary edema or other lung issues if a puppy is having breathing problems. However, a murmur by itself in a clinically normal puppy might not necessitate X-rays until something is confirmed or if there's any sign of trouble.
- **Blood pressure measurements:** High blood pressure is rarely an issue in puppies, but measuring blood pressure might be relevant if an older dog's murmur is being evaluated (in puppies, mostly relevant to rule out high blood pressure as a cause of a certain murmur characteristic, which is uncommon).
- **Pulse oximetry or blood gas:** If a puppy has a complex defect causing poor oxygenation (like a right-to-left shunt), measuring oxygen saturation can provide evidence of that (cyanotic heart disease). For instance, Tetralogy of Fallot puppies have low oxygen levels.
- **Cardiac catheterization/Angiography:** This is invasive and usually reserved for when an intervention is planned (like a balloon dilation) or in complex cases to gather more info. It's not commonly done just for diagnosis if echo can give the needed information.

**From Diagnosis to Action:** Once the cause of the murmur is identified via echo (or other tests), the veterinarian or cardiologist will discuss what it means and what to do next:

- If it's an innocent murmur the echo will show a normal heart, maybe just high flow. In that case, the conclusion is that no treatment is needed; just recheck down the road if needed.
- If it's a specific defect like SAS, PS, VSD, etc., the discussion turns to management (medical therapy, possible surgical or catheter interventions for some, expected outlook).
- They may also recommend checking littermates if a genetic defect is found (breeders often will have all puppies screened if one has a defect, to ensure others don't silently have it).
- For breeders, a diagnosis in a puppy means looking back at the parents (e.g., if a pup has SAS and both parents had normal heart exams, it's valuable information for future breeding decisions – perhaps one parent is a carrier and produced this, which is considered in breeding strategy or maybe avoid repeating that breeding).

**Collaboration in Care:** The diagnostic process for a murmur can thus involve:

- The primary care vet (for initial detection and follow-up).
- A specialist (cardiologist for definitive diagnosis).
- Possibly the breeder (if the puppy is still under the breeder's care or to inform them for genetic implications).
- The owners, who need clear guidance and support as they learn about what a murmur means for their beloved pet.

In summary, diagnosing a heart murmur is a stepwise process: hear it, characterize it (grade, timing, location, etc.), and then if needed, image it and measure it. The stethoscope gives hints, but the echocardiogram often gives the answers. In Golden Retriever puppies with their predispositions, a careful classification of the murmur by a vet will often lead to an early suspicion of SAS or other defects if present, and referral to a cardiologist to confirm. On the other hand, if everything points to a benign murmur, vets will still keep a watchful eye but spare the puppy unnecessary procedures. The next section will move into the perspective of breeders and what steps they take to prevent and address heart murmurs in puppies.

# Breeder Considerations – Screening, Parental Testing, and Actions When Murmurs are Detected

Breeders of Golden Retrievers, especially those dedicated to the health and well-being of the breed, have a significant role in managing and mitigating the risk of congenital heart issues. This part of the guide is particularly tailored to breeders and those interested in how responsible breeding can intersect with veterinary cardiology. We will discuss the screening methods available (such as OFA certifications and echocardiographic evaluations), the importance of parental testing and what it entails, the limitations of these screenings (why even the best efforts can't catch everything), and the appropriate actions a breeder should take if a murmur is discovered in a puppy before it goes to a new home.

**Routine Cardiac Screening for Breeding Dogs:** Ethical Golden Retriever breeders typically incorporate heart exams into their pre-breeding health checks. The Orthopedic Foundation for Animals (OFA) is a registry in the United States that offers certification for cardiac health (among other health areas). The traditional OFA cardiac exam involves a **board-certified veterinary cardiologist** listening (auscultation) to the dog for any heart murmurs or arrhythmias. If the dog is over a certain age (usually 12 months or older) and the cardiologist hears no murmur or any abnormal sound, the dog can receive an OFA cardiac clearance, often recorded as "Normal."

However, given the challenge of detecting mild SAS by auscultation alone, many breeders (and cardiologists) recommend an **echocardiographic examination** for breeds at risk of congenital heart diseases like SAS. There is even an "Advanced Cardiac" certification through OFA which indicates that an echocardiogram with Doppler was performed. For Golden Retrievers, this can be particularly valuable:

- An echo can measure the flow velocity in the left ventricular outflow tract and might catch a dog that has a mildly elevated velocity suggestive of a very mild SAS that perhaps isn't audible with a stethoscope.
- It can also verify that the dog has no other abnormalities (like a tiny VSD or a tricuspid valve issue) that hearing alone might miss.
- Many breeder clubs or the Golden Retriever Club of America's code of ethics either strongly recommend or require a cardiac clearance (at least auscultation by a cardiologist) for breeding stock. Increasingly, knowledgeable breeders choose to do the ultrasound as well for that extra assurance, even though it's more costly and time-consuming.

**Timing of Parental Screening:** Because of SAS's nature (progressive during the first year of life), a Golden Retriever can be born with mild SAS that isn't evident until it matures. Therefore:

• Breeding dogs are often first screened around 12 months of age or shortly thereafter. If a dog had a problem like moderate SAS, by a year old it would likely

be apparent as a murmur. If the dog passes at 12-18 months with no murmur and normal echo, that's a good sign.

- Some breeders will repeat a cardiac exam on their breeding dogs periodically, say at 2 or 3 years old, to ensure nothing has changed (this might catch the rare case of a very late-developing mild SAS or an acquired cardiac issue).
- Note that if a Golden retriever had only a very mild SAS that became detectable after 1 year, it might already have been bred (some breeders breed at age 2). So it's possible that even with initial screening, subtle cases slip through – a reminder that no method is infallible.

**Parental Genetic Testing:** As of now, there is no direct genetic test (like a DNA swab test) for SAS or most congenital heart diseases in Goldens. So breeders rely on phenotypic testing (actual heart exams) to try to infer genetic health. In breeds where a single gene mutation is known for a disease, breeders can do DNA tests to avoid carriers. But for heart defects in Goldens, research hasn't yet yielded a straightforward gene test (we'll discuss the state of genetics in Part VII). Because of this, breeders look at family history: if certain bloodlines have produced multiple cases of SAS, a conscientious breeder might avoid those lines or at least ensure multiple generations have been screened clear.

**Limitations of Screening:** Even when both parents have normal heart clearances, there is still a possibility for puppies to be born with a heart defect. Why? Several reasons:

- **Polygenic or Complex Inheritance:** If a condition is caused by multiple genes, a dog can carry some risk factors without showing disease. Two healthy parents might each carry some genetic components that, when combined in a puppy, lead to that puppy having the defect. The parents are essentially asymptomatic carriers.
- **Incomplete Penetrance:** This means a dog could have the genetic makeup to develop SAS but perhaps didn't due to lucky modifiers or less severe expression, yet it can pass on those genes to puppies who might express it more strongly.
- **New Mutations:** It's possible (though probably rare) that a new spontaneous mutation arises in a puppy that neither parent had, causing a defect.
- **Detection Limits:** As noted, a mild SAS may produce so little turbulence that even a cardiologist might call the dog clear on auscultation. If that dog is bred, it could still pass on SAS genes. The same goes for a very mild tricuspid dysplasia that doesn't cause a murmur in the parent, or an ASD that went undetected.

• Extrinsic factors not accounted for: Environmental or developmental factors in utero could also play a role in some defects (though for SAS and such, genetics is strongly suspected as primary).

Because of these limitations, even the best breeders occasionally have a puppy born with a heart defect. It is not necessarily that the breeder was negligent; it often reflects the genetic complexity of these conditions. What sets a responsible breeder apart is how they handle such occurrences and how they adjust their breeding program with that knowledge.

**Screening of Puppies:** Some breeders will have a veterinary cardiologist examine an entire litter of puppies before they go to new homes. This is especially true if the breed is known for issues (some Newfoundland breeders do this for SAS, for instance) or if a particular breeding might have higher risk. A cardiologist can auscultate each puppy (and even do mini-echos on each if warranted) at around 7-8 weeks. This can ensure that any puppy with a significant murmur or defect is identified early. However, not all breeders do this due to cost and availability of cardiologists. Often, the first check is a general vet exam at 6-8 weeks, and if the vet hears a murmur, then further steps are taken.

**Responsible Actions for a Detected Puppy Murmur:** If a breeder or new owner finds out a young puppy has a murmur, the following are considered best practices:

- **Full disclosure:** The breeder should inform the potential owner (if not yet sold) about the finding. Transparency is crucial. A reputable breeder would never hide a murmur just to sell a puppy.
- **Diagnostic follow-up:** The breeder should ideally arrange for a thorough examination by a specialist before deciding the puppy's future. For instance, if a vet hears a Grade III murmur in a 8-week-old Golden puppy, the breeder might hold onto that puppy a bit longer and have a cardiologist perform an echocardiogram at, say, 10-12 weeks to diagnose the cause. Alternatively, if immediate cardiology consult is not feasible, they might adopt a wait-and-recheck approach (keeping the puppy until 12 or 16 weeks to see if it resolves, which would suggest innocence).
- **Deciding on placement:** Depending on the results, the breeder has to make ethical decisions:
  - If the murmur is innocent and resolves, the puppy can likely go to its new home a bit later than usual, with reassurance it's healthy.
  - If the murmur is due to a mild defect that is not life-threatening (say a tiny VSD or mild SAS), the breeder should inform the new owner. Often, such

puppies can still be placed in loving pet homes, but typically under a neuter agreement (they shouldn't be bred) and possibly with a health guarantee or a clause that the breeder will assist with any medical costs related to it. Some breeders might discount the price or give the puppy for free to a good home aware of the condition.

- If the defect is serious (for example, a Golden puppy with a diagnosed severe SAS or a combination defect that will likely shorten its life significantly or require costly surgery), many breeders will choose to keep the puppy themselves and manage its condition rather than sell it, or they might find a very special home willing to take on the dog's medical needs (often at no cost). Some breeders might even elect humane euthanasia in extremely severe cases where the puppy would suffer (though that is usually a last resort for only the worst, hopeless cases).
- Return/Refund Policies: In many regions, if a congenital defect is discovered soon after purchase (often within a year), puppy "lemon laws" or contract terms allow the buyer to return the puppy for a refund or have the breeder pay for treatment. A responsible breeder's contract will outline what happens in such cases. However, most families, once attached to a puppy, do not want to return it they want it treated. A good breeder will then step in to either fund or help fund the needed care, or offer to take the puppy back and care for it if the owner can't. The point is to ensure the puppy is looked after and the owner is not left alone facing a medical crisis.
- Informing the breeding program: If a puppy is found to have a congenital heart defect, the breeder will revisit whether the parent dogs should be bred again together or at all. For example, if a litter produces an SAS puppy, many breeders will not repeat that breeding combination. They may still breed the parents to different mates, but with caution and maybe additional screening of those mates or their relatives. Some breeders might retire a dog from breeding if it produced a serious defect, especially if it's something thought to be highly heritable. Each breeder might handle it a bit differently, but the underlying principle is to reduce the chance of it happening again.
- **Use of Organizations:** Breeders often work with organizations like the Golden Retriever Club or foundations. For heart issues, there might be databases to report defects which help track genetic lines (although much of that is informal or within breeder communities).

**Screening Limitations Example:** The AoSA study we cited earlier indicated that some Goldens could have mild SAS that isn't identified in puppyhood or even early adulthood easily. So a breeder might do everything "right" (parents cleared via echo and

auscultation) and yet a puppy is born with moderate SAS. This can be disheartening. The knowledge that SAS is polygenic and not fully detectable means breeders must make decisions with incomplete information. Some very diligent breeders will avoid using dogs from lines where any SAS has popped up, trying to select for those lines that have had many generations of clear dogs. But given the silent carrier issue, it's always a calculated risk. The Golden Retriever community often emphasizes breeding only dogs with OFA heart clearances as a baseline to at least cut down the incidence drastically from what it would be without any screening.

#### Other Breeder Tools and Considerations:

- **OFA Database:** Breeders and buyers can verify on the OFA online database if a breeding prospect has a heart clearance. This public information adds accountability.
- **Cardiologist evaluation at puppy exams:** If possible, breeders schedule a vet cardiologist to check puppies. In some areas, there are heart clinics (for example at dog shows or club events) where litters can be evaluated at a reduced cost.
- Holter or ECG screening for arrhythmias: Not typically relevant for murmurs, more for breeds prone to arrhythmias (Boxers, etc.). But not needed in Goldens as routine.
- **Necropsy:** If unfortunately a puppy dies from a suspected heart issue, a breeder may get a post-mortem exam to confirm what the defect was. This can inform how genetic it might be (for instance, identifying SAS vs something like a myocarditis would be important to know if it was genetic or not).

In conclusion to this part, responsible Golden Retriever breeders strive to ensure that both parents are heart-healthy to minimize the risk of puppy murmurs. They understand that no method is perfect, but by obtaining proper certifications and often going the extra mile with echocardiograms, they significantly reduce the incidence of serious heart disease in their litters. When a murmur does crop up in a puppy, they follow an ethical approach: diagnose, disclose, and decide in the best interest of the puppy and the breed. Breeders serve as an important first line of defense in the battle against hereditary heart conditions, and their cooperation with veterinarians and researchers is pivotal. And speaking of hereditary conditions, we will now transition to the final part of our guide, which looks at what is currently known (and unknown) about the genetic basis of these heart murmurs in Goldens, focusing on SAS, and what research is ongoing.

# Genetics of Pathologic Murmurs in Golden Retrievers – Current Understanding and Research Directions

Why do some Golden Retrievers develop congenital heart defects like subvalvular aortic stenosis (SAS) while others do not? Understanding the genetic underpinnings of these conditions is critical for making progress in prevention. In this section, we explore what is known about the inheritance of key heart defects in Golden Retrievers, especially SAS, and highlight the research that has been done or is underway. We will also touch on genetic insights from other breeds (like Labrador Retrievers with tricuspid dysplasia or Newfoundlands with SAS) to see how they inform the Golden Retriever situation. Finally, we will outline areas where further study is needed.

**Heritability of SAS in Golden Retrievers:** SAS in Goldens is clearly an inherited condition, as evidenced by higher-than-average incidence in certain families and lines. Early observations by veterinarians and breeders noticed that SAS tends to pop up in certain pedigrees. However, the exact mode of inheritance has been elusive. Unlike a simple single-gene disorder (like some coat color traits or certain diseases where one gene is responsible), SAS behaves in a complex way:

- It does not follow a straightforward dominant or recessive pattern that pedigree analysis can easily pin down. There have been cases of two perfectly healthy parents (with no murmurs, etc.) producing a puppy with severe SAS – which suggests that if it's genetic, it might require contributions from both sides (pointing to a recessive trait or polygenic trait).
- On the other hand, if it were a simple recessive, you might see a quarter of puppies affected when two carriers are bred, and clear evidence of that ratio hasn't consistently been observed or documented.
- Some studies (including one on another breed, the Dogue de Bordeaux, which has both SAS and tricuspid dysplasia issues) have proposed an autosomal recessive inheritance with incomplete penetrance. "Incomplete penetrance" means not every dog that has the gene mutation will show the disease – some may carry it but not express it fully.
- Another theory is polygenic inheritance meaning multiple genes, possibly many, each add a bit to the risk. A puppy that ends up with enough of the "risk" versions of these genes (and maybe certain environmental triggers) develops the disease. Polygenic diseases also tend to have a spectrum of severity, which fits SAS (mild to severe).

Research on Newfoundlands (another SAS-prone breed) decades ago already pointed to polygenic or at least not simple Mendelian inheritance. Golden Retrievers are thought to be similar, which is why eliminating SAS has been challenging.

#### **Current Genetic Research Findings:**

- One of the more concrete genetic findings in recent years was in Newfoundlands: researchers identified a variant in a gene called **PICALM** associated with SAS in Newfoundlands. This was a single codon insertion mutation. In one study, they found this variant had a high frequency in Newfoundlands (meaning many dogs had it, including some without SAS), suggesting it might be a risk factor but not the sole cause or could even be a passenger variation in some lines. When they looked at Newfoundlands in Europe, the correlation wasn't as strong, leading to questions about whether that variant is truly causative or just associated in one population. Essentially, that research taught us that even finding a gene of interest can lead to more questions: the PICALM mutation might play a role in some Newfies, but since many dogs with it were healthy (and some SAS dogs didn't have it), SAS is likely polygenic in Newfies too.
- For Golden Retrievers specifically, studies have been and are being conducted using **genome-wide association studies (GWAS)**. A GWAS involves scanning the DNA of a group of affected Goldens and comparing it to unaffected Goldens to see which genetic markers are more common in the affected ones. According to a recent review of SAS genetics, a GWAS in Golden Retrievers identified a region on **chromosome 13** that was statistically associated with SAS. This suggests that somewhere on that chromosome, there may be a gene (or genes) influencing SAS development. Interestingly, similar studies in Rottweilers and Newfoundlands also indicated something on chromosome 13. This raises a hypothesis: could there be a common genetic risk factor in these large breeds that predisposes them to SAS? If so, it might be an ancient mutation or a gene that's crucial in heart development.
- Researchers have examined pedigrees of Goldens with SAS and have indeed found that unaffected dogs can produce affected puppies (implying they were carriers). In one published pedigree analysis, the patterns supported a recessive inheritance with incomplete penetrance for SAS in those specific families studied.
- Another interesting link: because SAS in dogs shares some similarities with a human condition (subaortic stenosis in children, though in humans it's often part of complex syndromes or not as common), researchers have looked at developmental pathways. The notion of the **aortoseptal angle (AoSA)** being steep in puppies that develop SAS is one example. It suggests that perhaps certain developmental shapes of the heart predispose to the lesion forming, which might be under genetic control. If puppies have a certain conformation of the aortic outflow tract (like the alignment of the septum and aortic valve), that could be an inherited anatomical trait that sets the stage for SAS. The study on Golden Retriever puppies measuring AoSA showed that some puppies had an abnormal angle that correlated with later SAS development. This kind of

phenotype (physical trait) could be influenced by genes that govern cardiac structure formation.

- Tricuspid Valve Dysplasia (TVD) in Labradors and others: For context, Labrador Retrievers have a high incidence of TVD (somewhat analogous to Goldens with SAS). Research in Labs identified a genetic locus on dog chromosome 9 associated with a severe form of tricuspid malformation (similar to Ebstein anomaly in people). This suggests a major gene could be at play there (though as of now, there isn't a direct DNA test for it publicly, indicating more work is needed). The Labrador TVD might be simpler (like maybe one major gene of large effect) or still polygenic but with at least one strong gene found.
- **Applying to Goldens:** Goldens can also get TVD, but much less commonly. If a Golden were to have TVD, and given Labs and Goldens share ancestry if you go back many generations (retrievers), one could wonder if they might share the same mutation possibility. There's no published evidence of that yet specifically for Goldens. But it's plausible the genetic cause of TVD in Labs, if identified fully, might inform Golden cases of TVD if any.
- For other defects like PS or PDA, those have known breed predispositions but usually not in Goldens. For example, a genetic mutation has been found for one type of PDA in Poodles (a specific gene that predisposes, though PDA is often complex too). PS in some breeds has a suspected genetic basis but not one pinpointed gene for most.

# Ongoing Research Efforts:

- Several veterinary research institutions (like the University of California, Davis; Cornell University; North Carolina State University; etc.) have or are conducting studies on canine congenital heart diseases. For Goldens, researchers like veterinary cardiologists and geneticists often call for DNA samples from affected dogs and their relatives to build a database.
- The Golden Retriever Foundation (a charitable arm of the breed club) has been known to fund research into health issues including heart disease. For example, they might support studies aimed at identifying genetic markers for SAS or supporting cardiac screening data collection.
- A combined approach is often being used: genetic studies plus detailed clinical data (like those AoSA measurements or following puppies as they grow) to understand how genotype leads to phenotype. Collaboration between breed clubs and researchers is common; Golden Retriever owners are often very willing to volunteer their dogs for studies knowing it could help the breed.

 It's possible that in the next few years, larger studies involving whole genome sequencing of Goldens with SAS could reveal candidate mutations (like the Newfie PICALM story or others). The challenge is ensuring enough samples and a clearly defined affected vs unaffected group to get statistically significant results.

**Why No Test Yet?** People might ask, if breeders have been dealing with SAS for decades, why don't we have a DNA test for it like we do for some other diseases? The answer lies in that complexity:

- When it's polygenic, there isn't one "bad gene" to test for. It could be a combination of many.
- If it's one gene with incomplete penetrance, identifying it is harder because it doesn't show a perfect correlation in populations.
- The cost and effort to find polygenic causes is high, requiring many samples and advanced analysis.
- As we saw, one attempt found a gene (PICALM) but that alone wasn't the silver bullet; it explained some but not all cases.

So research is iterative – each study peels back a layer. At the moment, breeders are basically practicing "selection" without a genetic test: they avoid breeding dogs that had SAS or produced it. Over many generations, this should decrease incidence if diligent, but it can be slow, especially if carriers aren't identifiable until they produce an affected pup.

**Trends and Hopes:** With modern genomics, there is hope that eventually a set of genetic markers (like a panel of SNPs) could be developed to estimate a Golden's genetic risk for SAS. This would be akin to how some human diseases are assessed by polygenic risk scores. It's complex, but not impossible. If, say, 5-10 genes each contribute a bit to SAS risk, a DNA panel might check those and give a risk estimate. Breeders could then make more informed decisions beyond just phenotypic screening. That's a future goal.

# **Other Congenital Heart Defects Genetics:**

- **PDA in Goldens:** No specific evidence Goldens have a unique genetic cause for PDA; it seems sporadic in the breed.
- VSD/ASD: These often occur in isolation in any breed; some familial ties have been noted in certain dogs (like some lines of Springer Spaniels for VSD), but not heavily documented in Goldens.

• Because SAS overshadows others in Goldens, most genetic talk in this breed is about SAS.

# Summary of Genetic Knowledge for SAS in Goldens:

- It's heritable and breed-associated.
- Likely involves multiple genes.
- One or more major gene loci have been suspected (like something on chromosome 13).
- No definitive causative mutation identified yet for Goldens (unlike Newfies which have a candidate in PICALM).
- Breeding strategies currently rely on eliminating affected individuals from the gene pool and not breeding carriers (to the best of knowledge).
- Researchers are actively working on it, with some promising leads, but more work is needed.

**TVD (Tricuspid Valve Dysplasia) Genetics:** As noted for Labradors, evidence suggests a genetic component. In one study, Labrador TVD mapped to a region on chromosome 9, and another identified a possible autosomal dominant inheritance with incomplete penetrance in some lines (though not confirmed conclusively). For Golden Retrievers, TVD is so uncommon that it hasn't been studied specifically, but any case in a Golden might have a genetic basis similar to Labs. If a Golden line produced TVD, breeders would likely avoid doubling up on that line. Interestingly, some Dogue de Bordeaux dogs have both SAS and TVD issues, suggesting in that breed a possible shared genetic syndrome or close linkage of genes.

**Importance of Genetic Research:** For families and vets, the benefit of genetic research is long-term. It may not help an individual puppy with a murmur today, but it could reduce such incidents for the breed in the future. For researchers, canine genetic studies can also shed light on heart development in general – dogs like Goldens with SAS can serve as a model for understanding similar conditions in humans. There's a mutual benefit: solving canine heart defect genetics can improve canine health and potentially human health (One Health perspective).

# **Ongoing or Needed Research Summary:**

- Pinpointing specific gene mutations for SAS in Goldens through large-scale DNA analysis.
- Developing genetic tests or marker panels for breeders to use in selection.

- Investigating if any environmental factors influence expression of SAS (e.g., rapid growth might exacerbate severity – this is speculative but worth exploring).
- Encouraging breeders to contribute data to help researchers establish inheritance patterns (for example, detailed pedigree analysis combined with modern DNA testing).
- Cross-breed studies to see if, say, Goldens and Newfies share a gene a finding that could make a test applicable across multiple breeds.
- Funding and support from breed clubs to sustain this research, because it requires many years and many dogs' participation to draw firm conclusions.

As of 2025, the state of knowledge is that we acknowledge SAS in Golden Retrievers as a complex genetic disease that we have to manage by careful breeding and clinical vigilance, while science works on unraveling its mystery. Each year brings a little more understanding, and breeders and researchers often cooperate by sharing data and DNA samples.

**Tricuspid Valve Dysplasia (TVD) Recap:** In Labrador Retrievers, TVD clearly runs in families, and research has pointed to some genetic basis (with hints at specific chromosomes). Goldens rarely have TVD, but if they do, similar principles apply – ideally those dogs aren't bred, and their relatives are monitored. It's possible that as genetic studies progress for Labs, any discovered genetic markers might also be tested in Golden Retrievers as a precaution.

#### **Future Research Needs:**

- Larger genetic studies: More samples from Goldens worldwide with SAS (and their unaffected relatives) to improve the power of detecting genetic differences. International collaboration could gather enough data to reach definitive conclusions.
- **Functional studies:** If a gene is suspected (like the region on chromosome 13), scientists need to investigate what that gene does. For example, does it influence heart valve development? Tissue modeling or animal models could be used to see how a mutation leads to the SAS lesion.
- **Improving screening:** On a different note, research could also focus on improving early screening methods in puppies. For instance, maybe certain blood biomarkers or advanced imaging techniques could identify pups with mild SAS even before a murmur is obvious. This ties into genetics because high-risk pups (if we know the genetics) could be targeted for extra monitoring.

 Interventional research: Though not genetics, it's worth mentioning – research into better treatments (like a more effective way to address SAS obstruction) is needed. Genetic research might even pave the way for novel therapies (if a pathway is identified, a drug might be developed to slow down the fibrous tissue growth in SAS, for example).

To wrap up, the genetic aspect of heart murmurs in Golden Retriever puppies is a frontier of both challenge and hope. While the inheritance is complex, the concentrated efforts of the veterinary genetics community are gradually shedding light on it. Breeders and researchers together form the alliance that will ultimately crack the code of SAS and other congenital heart issues, enabling more targeted prevention.

#### **Conclusion: Key Takeaways and Future Directions**

#### For Families (Puppy Owners):

- It's common for young puppies to have a soft heart murmur; roughly a quarter of puppies might have one that they will outgrow. So if your vet says your Golden Retriever puppy has a murmur, don't panic – it could be an innocent murmur that disappears in a few months. Follow your vet's advice for monitoring and rechecks.
- Know the warning signs of a potentially serious murmur: if a murmur is loud (high-grade), persists beyond about 4-6 months of age, or if your puppy shows symptoms like tiring easily, rapid breathing, coughing, or fainting, it needs further investigation by a veterinarian (ideally a cardiologist).
- The definitive way to understand a murmur is with an echocardiogram (ultrasound of the heart). Many murmurs turn out to be benign, but if it's something like subaortic stenosis or another defect, catching it early allows for proper management or even surgical correction in some cases.
- If your puppy is diagnosed with a congenital heart defect, work closely with a vet cardiologist. Many heart conditions can be managed or treated. For example, a patent ductus arteriosus can often be fixed with surgery, and even conditions without a cure (like SAS) can be managed with medication and lifestyle adjustments to improve quality of life.
- Communicate with your breeder about any findings. Reputable breeders want to know if a puppy from their litter has a health issue and will often support you they might have advice, or they may have contract provisions to help with medical costs or allow returning the puppy if needed (though most families choose to keep and treat the pup).

Remember that a puppy with a heart murmur is still the same loving companion.
 With proper care and informed attention, many puppies with murmurs (even some with heart defects) can live happy, active lives. The diagnosis is just something to be aware of and manage with your vet's guidance.

#### For Veterinary Professionals:

- In pediatric exams, take the time to characterize any murmur thoroughly. Note the murmur's grade (intensity I–VI), timing (systolic, diastolic, continuous), point of maximal intensity, and quality. These details guide your differential diagnosis and urgency of further diagnostics.
- Keep breed predispositions in mind. A murmur in a Golden Retriever puppy should prompt consideration of subaortic stenosis if it's left-basilar, whereas a right-sided murmur might point to a ventricular septal defect or tricuspid dysplasia. Use the murmur's characteristics to narrow the possibilities, but confirm with diagnostics.
- Use a stepwise approach for workup. A very soft murmur in a young (6–8 week) puppy with no other abnormalities can be monitored with a follow-up exam in a few weeks. However, a loud murmur, or any murmur accompanied by poor growth or clinical signs, warrants prompt investigation (including referral for an echocardiogram). Continuous or diastolic murmurs in a puppy are rare and almost always pathologic these should be treated as urgent referrals (e.g., suspect PDA if continuous).
- Collaborate with veterinary cardiologists. Early referral for echocardiography not only provides a definitive diagnosis but also lets you and the pet owner benefit from specialized expertise. Stay in communication with the cardiologist to learn the outcome and recommended plan, as this will enhance your own understanding for future cases.
- Educate and reassure pet owners. Explain in plain language what a murmur is and why you recommend either watchful waiting or further testing. Owners often fear the worst when they hear "heart murmur," so your guidance can help them make informed decisions without undue panic. Conversely, if you suspect a serious condition, be honest about it and outline the next steps clearly (owners appreciate a frank but compassionate approach).
- Stay updated on advancements in congenital cardiac care. Be aware of breedspecific screening programs (like OFA heart certifications) and new treatment options (for example, improved surgical or catheter-based interventions for defects). This enables you to provide current, best-practice advice to both puppy owners and breeder clients.

#### For Breeders:

- Prioritize cardiac health in your breeding program. Ensure that your Golden Retriever breeding dogs undergo thorough heart screening by a veterinary cardiologist. Ideally, this includes an auscultation and a Doppler echocardiogram to rule out silent mild subaortic stenosis or other defects. Obtain official clearances (such as OFA cardiac certification) for your dogs before breeding.
- Understand that even two heart-clear parents can produce a puppy with a defect, due to the complex genetics involved. What defines a responsible breeder is the response: be transparent with puppy buyers if a murmur is detected, and take appropriate action. This may include having the puppy evaluated by a cardiologist, delaying placement until you have more information, or rehoming the puppy with full disclosure of its condition.
- Support your puppy owners. If a pup from your litter is found to have a congenital heart disease, work with the owner—offer guidance, refer them to specialists, and honor any health guarantee you provided. Often, ethical breeders will help cover the cost of diagnostics or even take the puppy back if the owner cannot care for a special-needs dog (though in many cases the owner will choose to keep the puppy, appreciating the breeder's integrity and assistance).
- Incorporate what you learn into future breeding decisions. If a particular mating produced a heart defect, consider not repeating that breeding. Gather information: for instance, if one of the parent dogs has produced murmurs in puppies via different pairings, that dog might carry undesirable genes and should potentially be retired from breeding. Share this information with the breeding community openness can prevent others from unknowingly doubling up on a risky line.
- Utilize available resources and contribute to research. Participate in breed club health surveys and databases that track incidences of congenital heart issues. If researchers request DNA samples or family histories from dogs with heart defects, cooperate for the greater good of the breed. By aiding research, you increase the likelihood that future Golden Retrievers won't face the same problems.
- Remember that as a breeder, your goal is to improve the breed. Breeding away from heart defects is a long-term commitment: through careful selection, transparency, and use of scientific tools as they become available, you can help reduce the incidence of murmurs and congenital heart disease in Golden Retrievers over time.

#### For Researchers:

- Golden Retrievers with congenital heart diseases like SAS offer a valuable model for genetic study. Leverage the breed's well-documented pedigrees and the willingness of owners/breeders to participate in studies. Large sample sizes and collaboration across institutions will be key to identifying the polygenic factors at play.
- Build on existing findings. Prior studies have implicated certain chromosome regions (for example, a locus on canine chromosome 13) and even a specific gene variant in other breeds (like the PICALM gene in Newfoundlands) for subaortic stenosis. Investigate whether similar genetic markers are present in Goldens, and explore the interplay of multiple genes. Modern techniques like genome-wide association studies and whole-genome sequencing can uncover risk alleles that were previously elusive.
- Work collaboratively across breeds and disciplines. Since SAS affects multiple large breeds, comparative studies might reveal common genetic denominators. Engaging cardiologists, geneticists, and even human medicine researchers (because of parallels to human pediatric cardiac conditions) can provide new insights and funding avenues.
- Focus on translational impact. Developing a genetic test (even if polygenic) for risk of SAS in Golden Retrievers would be a huge advancement for breeders. Consider researching polygenic risk scores or a panel of DNA markers that could stratify dogs as low or high risk. Also, studies on early detection (such as advanced imaging or biomarkers in blood) could help veterinarians identify at-risk puppies sooner.
- Share your research findings with the community. Publish in open-access journals when possible and communicate in breed club forums or veterinary conferences. When breeders and veterinarians are informed about the latest discoveries, they can immediately apply that knowledge in the field (for example, adjusting breeding strategies or screening protocols).
- Look ahead to innovative therapies. While genetic research primarily aims at prevention, understanding the molecular pathways involved in SAS or valve dysplasias could open doors to novel treatments. In the distant future, gene editing or targeted molecular therapies might be conceivable. In the near future, better prophylactic or early interventions might arise from knowing which dogs are genetically predisposed (such as tailoring exercise or diet for pups likely to develop issues).

**Future Outlook:** Advances in veterinary medicine and genetics are steadily improving outcomes for puppies with heart murmurs. In the coming years, we can expect:

- Improved Early Detection: New technologies (like digital stethoscopes with Al analysis) may help differentiate innocent from pathological murmurs with greater accuracy during routine exams, ensuring timely referrals.
- **Genetic Breakthroughs:** Continued research may yield genetic screening tools for conditions like SAS in Golden Retrievers. Breeders could one day use genetic tests to make informed mating decisions, significantly reducing the incidence of severe heart defects.
- **Better Treatments:** Veterinary cardiology techniques are continually advancing. We anticipate refinements in interventional procedures (for example, better balloon valvuloplasty techniques or novel stent placements) and medications that will enhance the quality and length of life for dogs with congenital heart disease.
- **Breed Health Progress:** As awareness grows, more Golden Retriever breeders will adhere to rigorous health screening, and buyers will increasingly expect it. Over generations, this can lead to a decline in congenital heart issues in the breed. The cooperative efforts of breeders, veterinarians, and researchers will be instrumental in this positive trend.
- One Health Perspective: Research on canine heart diseases not only helps dogs but can also contribute to human medicine. Discoveries in Golden Retrievers might shed light on similar congenital heart conditions in children, creating a reciprocal benefit. This could attract broader support and resources for studying and addressing these murmurs.

In summary, a heart murmur in a Golden Retriever puppy is a signal — sometimes benign, sometimes serious — that prompts us to pay attention to the heart. By understanding the context and implications of murmurs, families can react appropriately (with neither undue alarm nor complacency), veterinarians can diagnose and guide effectively, breeders can make wise choices to reduce genetic risk, and researchers can continue to unravel the mysteries behind these conditions. Together, these efforts ensure that Golden Retriever puppies, adored for their gentle and joyful nature, have the best chance at healthy, active lives with hearts as sound as their spirits.